Haptic Interaction with 3D Ultrasound Data
The e-Touch sono System

Touch Your Baby Before He or She is Born

Walter A. Aviles
Thomas G. Anderson
Novint Technologies
http://www.novint.com

Abstract

The e-Touch sono™ system allows users to interactively feel and see 3D ultrasound images. This system is currently targeted for use in pre-natal imaging [1]. Parents are able to feel as well as see three-dimensional imagery. We have found that this increases both their understanding and their enjoyment of their child's ultrasound image. This has several important benefits. First of all, it allows physicians to more clearly explain the developmental process, progress and any complications. Second, it helps ease parental stress and anxiety over the progress of their child. Finally, it helps the all-important parent-child bonding process. Over time, the e-Touch sono system will be refined in order to be used for medical diagnosis, surgical planning, and intraoperative procedures.

Background

Ultrasound is a high-quality, reliable and cost effective medical diagnostic tool. It has been used for medical imaging and diagnosis purposes since the Second World War [2][3]. The first medical ultrasound systems, mirroring their roots in Sonar technology, required that the patient be immersed in water for imaging to occur. They also used "A-mode" presentation of the ultrasound data -- blips on an oscilloscope screen. The more familiar "B-mode" presentation of two-dimensional gray scaled images followed shortly thereafter. Ultrasonic imaging came into more common use in the clinical environment in the 1960s and 1970s with the introduction of compact hand-held scanners with real-time B-mode imaging capabilities. More recently, medical ultrasound systems capable of generating three-dimensional (i.e., volumetric) data and images have become available.

Some ultrasound systems generate the three-dimensional images by analyzing and combining a series of two-dimensional B-mode images gathered using a hand-held scanner outfitted with a position/orientation tracker. Other systems utilize a more sophisticated transducer design to allow three-dimensional data to be gathered without requiring any external transducer movement or tracking. These later systems are often referred to as "4D" systems because they allow three-dimensional data and imagery to be gathered in real-time. GE Medical Systems' Voluson 730 ultrasonic imaging system, for example, currently generates 16 three-dimensional images per second [4].

One of the most common uses of ultrasound is in obstetrics and gynecology. Ultrasound has made it possible to non-invasively study pregnancy from beginning to end. Diagnosis of complications of multiple pregnancy, fetal abnormality and placenta previa became possible with the use of ultrasound in the clinical environment. Moreover, ultrasound exams are generally considered safe at the power levels used for diagnosis. In addition to providing physicians with a useful diagnostic tool, ultrasonic imaging allows prospective parents to view their child's development.

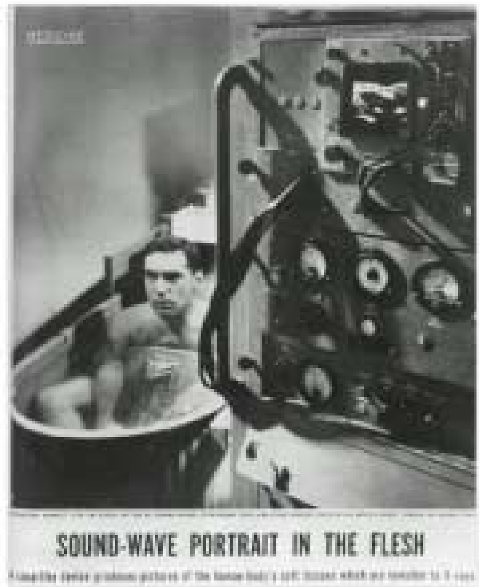

Figure 1 -- Water Immersion Motorized B-mode Scanner Circa 1954

3D Haptic Interaction

As part of our research and development, we have explored the use of haptic interaction in the understanding, use and modification of sensor-derived three-dimensional geoscientific [5] (e.g., seismic) and medical (e.g., CAT Scan or MRI) data. 3D ultrasound is particularly interesting because it is a safe and cost effective real-time imaging modality. Adding haptic interaction to 3D ultrasound promises to have many of the same benefits and features that we have seen before. Three-dimensional haptic interaction allows for the direct and unambiguous selection of parts of the ultrasound image for further exploration/analysis, simplified and direct six degree-of-freedom control of imaging tools such as interactive clipping planes and the use of an additional sensory channel or modality (i.e., touch) for understanding the data. These features hold the promise of simplifying and improving the clinical analysis of three-dimensional ultrasonic imagery by providing both a natural and a rich additional sensory interaction mode. Clearly, however, fully exploring and understanding the clinical impact and benefits of adding touch to ultrasound images will take time.

In order to help introduce haptic technology to the three-dimensional ultrasound community, we have developed a product, known as e-Touch(TM) sono, which is aimed at providing a more informative and enjoyable experience for parents when pre-natal 3D ultrasound images are taken of their child. Parents are able to feel as well as see three-dimensional imagery. We have found that this increases both their understanding and their enjoyment of their child's ultrasound image. This has several important benefits. First of all, it allows physicians to more clearly explain the developmental process, progress and any complications. Second, it helps ease parental stress and anxiety over the progress of their child. Finally, it helps the all-important parent-child bonding process.

This initial focus on parental interaction with ultrasound allows us to introduce haptic technology into the clinical environment in a way that has clear benefits today and allows the medical/diagnostic uses of haptic interaction with 3D ultrasound to be more gradually explored.

The e-Touch sono^{TM} System

The e-Touch sono System is a turnkey hardware and software system that allows users to interactively feel and see 3D ultrasonic images. Sono also allows the 3D images to be interactively cleaned-up and exported for the generation of 3D "hardcopy" or imagery.

Figure 2 -- The e-Touch sono System

The system consists of a computer workstation, a graphical display, a 3D touch interface device and the e-Touch sono software. Sono can also be run on a laptop computer system.

Figure 3 -- 3D Ultrasound Acquisition

The overall viewing and haptic interaction process begins when a pregnant women gets a 3D ultrasound. The data, in volumetric form, is transferred to the e-Touch sono system. The program automatically cleans up the data and applies default visualization and haptic parameters so that the "skin" surfaces in the data are visible and touchable. The parent or physician can then see and feel the surfaces of the child's face and body. Haptic skin textures are applied to the surfaces to improve the overall haptic experience. As shown in Figure 4, modern 3D ultrasound machines allow highly detailed images to be generated. Allowing parents to interactively control this imagery as well as "feel their baby" significantly adds to the overall educational, enjoyment and bonding aspects of the experience, in addition to easing anxiety about the health of the baby.

Figure 4 -- Side by Side Images of Pre-Natal Ultrasound & Baby

The key features of the sono system are:

- Reads data directly generated by GE Voluson 730 4D Ultrasound Systems
    - Cartesian Kretz V730 volume data file format via network or CDROM
    - Other data formats to be added
- Interactive visual display of 3D ultrasound data
    - Control color and opacity in real time
    - Real time rotate, translate & zoom
- Allows user to feel the ultrasound data in three dimensions
    - Surfaces (variable feel)
    - Volume properties (variable feel)
- Allows interactive clean-up of ultrasound data for 3D export in a variety of formats
    - Volume
    - Surface
    - Point
- Generates data for 3D "hardcopy" output
    - Several processes supported
- Generates data for 3D "take home" visualization
    - Several formats supported

Technical Overview

Data Pre-Processing

Three dimensional ultrasound data, like any real-world data, is noisy. Moreover, sampling resolution is such that voxel quantization is visible in the raw data obtained directly from the 3D ultrasound machine. As a first step in our visualization and haptic interaction process, we apply a standard set of three-dimensional filters to the ultrasound data. We utilize a 3D median filter followed by a gaussian smoothing process. The parameters of these filters were empirically tuned for use with the Voluson 730 system but need not be changed across machines or images. Figure 5 shows a typical ultrasound image before and after filtering.

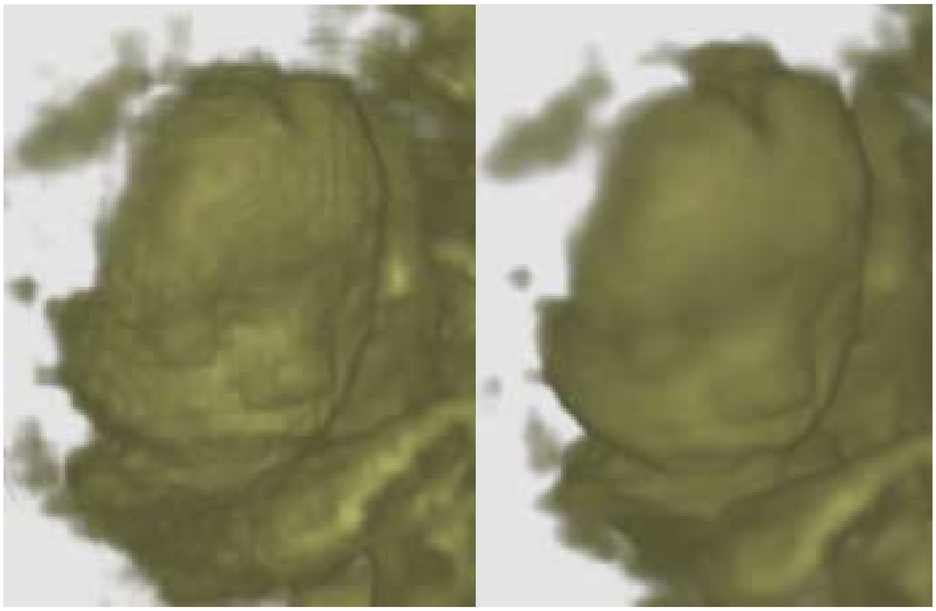

Figure 5 -- Typical 3D Ultrasound Before (Left) and After (Right) Pre-Processing

Visual and Haptic Rendering

The sono system is a volume-based visualization and haptic interaction tool. Both modalities operate on exactly the same data set in real-time. Sono can generate surface representations, however, to allow for physical ("rapid prototyping") models to be produced.

Visual Rendering. Visual volume rendering, allows internal structures to be viewed. Although this feature is not essential to the initial "parental" focus of the sono system, it is available for the exploration of the clinical diagnostic uses of the application. Volume visual rendering, being an image order technique, scales quite well with data set complexity. Modern consumer-level graphics cards provide solid interactive (i.e., greater than 10Hz) visual performance. As can be seen in Figure 5, the sono system's default visualization parameters are set so that low-density materials, such as amniotic fluid, are not visible.

Haptic Rendering. Like visual rendering, haptic rendering is also performed directly using the volume data. Two forms of haptic interaction are currently provided -- a full-volume viscosity force feedback algorithm and an isosurface rendering algorithm. The viscosity force is meant as an early tool for physicians to explore the overall volume data set. The technique generates a viscosity-like force that varies with the haptic "density" applied to a particular data set value. The isosurface rendering algorithm allows analytic isosurfaces to be felt. It is the primary haptic rendering algorithm used for parental education and bonding purposes. Both algorithms operate based only on data in the local neighborhood of the haptic interaction point. This means that overall volume size or complexity does not affect their operation.

The isosurface algorithm consists of two parts. In the first part, the isosurface is found and surface compliance forces (i.e., normal to the isosurface) are generated. This algorithm can treat even "thin shells" as non-permeable. This is important for 3D ultrasound fetal images since data for many parts of the image (e.g., face) is often in a thin shell form. Moreover, it is desirable to be able to vary the compliance model used for the surface independent of the whether or not the surface is part of a thin shell or deeper solid structure. For fetal imaging, the surface, for example, is rendered as quite soft or compliant using a simple spring model. The second part of the isosurface algorithm, applies surface texture (i.e., forces along the isosurface). We have tuned this model to provide a "skin-like" texture to surfaces.

Surface Model Generation. The sono system can also generate surface representations of the isosurface. It currently generates stereolithography format (i.e., STL) files of the isosurface for either the entire data volume or for particular views of the data. This data can be used for manufacturing three-dimensional models of the baby for diagnostic and "keepsake" purposes.

Conclusions

The e-Touch sono system allows three-dimensional ultrasound data to be felt as well as seen in real time. The initial focus of this application is to allow visual and haptic interaction with fetal images for parental education and bonding. This particular use of the system is quite compelling and has resulted in the commercial development and distribution of the sono system. Over time, we believe that, as the potential of haptic interaction for clinical diagnostic and analysis purposes is further explored, that sono will also have an important medical role.

Acknowledgements

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References

[1] Novint Technologies Incorporated, http://www.novint.com

[2] Woo, J, *A short History of the development of Ultrasound in Obstetrics and Gynecology*, http://www.ob-ultrasound.net/history.html

[3] *History of Ultrasound*, http://www.scmobileimaging.com/history.html

[4] GE Medical Systems, http://www.gemedicalsystems.com

[5] Aviles, WA and Ranta, JF, *Haptic Interaction with Geoscientific Data*, in Salisbury, JK and Srinivasan, MA (Eds), "Proceedings of the Fourth PHANTOM Users Group Workshop," AI Lab Technical Report No. 1675 and RLE Technical Report No. 633, MIT, November 1999, pp. 78-81.